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WATER PHENOLS NO. 1

Earl F. McFarren, et al

National Center for Urban and Industrial Health
Cincinnati, Ohio

1967

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Water Supply and Pollution Control

WATER PHENOLS NO. 1

STUDY NUMBER 28

ANALYTICAL REFERENCE SERVICE

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Public Health Service

56

WATER PHENOLS NO. 1

Study Number 28

Report of a Study Conducted by the

ANALYTICAL REFERENCE SERVICE

Earl F. McFarren, John M. Matthews
and Raymond J. Lishka
TRAINING PROGRAM
National Center for Urban and Industrial Health

Details of illustrations in
this document may be better
studied on microfiche.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of Disease Prevention and Environmental Control
Cincinnati, Ohio
1967

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Public Health Service Publication No. 999-WP-43

FOREWORD

The Analytical Reference Service (ARS) is conducted by the Training Program of the National Center for Urban and Industrial Health to evaluate laboratory methods in the environmental field. Cooperative studies by member organizations, who analyze identical samples and critically review methodology, provide the mechanism for:

> Evaluation of analytical procedures, including precision and accuracy, by comparison of the procedures and results reported by participating laboratories.
>
> Exchange of information regarding method characteristics.
>
> Improvement or replacement of existing methods by development of more accurate procedures, and development of new methodology for determination of new pollutional compounds.

Samples are designed to contain measured amounts of selected constituents. Decisions as to qualitative makeup are made by the ARS staff, the membership, and consultants. Notice of each study is sent to the entire membership. To those who desire to participate, a portion of the study sample is sent, along with data forms for reporting numerical values, a critique of the procedures used, comments on modifications, sources of error, difficulties encountered, or other pertinent factors. The results and comments received are compiled, and a report of each study is prepared.

Initially directed toward examination of water, studies now include air, milk, and food. Some studies are periodically repeated for the advantage of new members, to evaluate new methods, or to reevaluate existing methods.

The selection of studies is guided by the responses to questionnaires periodically circulated among the membership, which now includes 306 Federal, state, and municipal agencies; industries; universities; consulting firms; and foreign agencies.

James P. Sheehy
Chief, Training Program

ACKNOWLEDGMENTS

Michael J. Taras, Chairman, Joint Editorial Board of Standard Methods for the Examination of Water and Wastewater suggested this study to obtain data on the precision and accuracy of the methods for analysis of phenols, which appear in the 12th edition.

The American Public Health Association granted permission to copy the preliminary distillation step, page 229, the chloroform extraction method, pages 517 to 519, and the simplified aminoantipyrine method, pages 521 to 523, from the 12th edition of Standard Methods for the Examination of Water and Wastewater. Copies were sent to each participant.

Laurelia A. Lederer, Analytical Reference Service, key-punched the data, arranged for the analysis of the data by computer, and prepared the bar graphs.

STUDIES COMPLETED AND REPORTED

Water-Minerals	Calcium, magnesium, hardness, sulfate, chloride, alkalinity, nitrite, nitrate, sodium, and potassium. Studies completed in 1956, 1958, and 1961.
Water-Metals	Lead, copper, cadmium, aluminum, chromium, iron, manganese, and zinc; studies completed in 1957 and 1962. These same metals plus silver. Study completed in 1965.
Water-Fluoride	Fluoride in the presence and absence of interferences, with and without distillation by a specified procedure. Studies completed in 1958 and 1961.
Water-Radioactivity	Gross beta activity. Studies completed in 1959 and 1961. Gross beta and strontium-90 activity. Study completed in 1963.
Water-Surfactant	Surfactant in various waters. Studies completed in 1959 and 1963.
Water-Oxygen Demand	Biochemical oxygen demand and chemical oxygen demand. Study completed in 1960. Chemical oxygen demand. Study completed in 1965.
Water-Trace Elements	Arsenic, boron, selenium, and beryllium. Study completed in 1962. These same metals plus vanadium. Study completed in 1966.
Freshwater Plankton	Evaluation of the precision and accuracy obtainable by the use of various methods of plankton counting and identification. Study completed in 1964.
Water-Nutrients	Silicate, phosphate, ammonia nitrogen, organic nitrogen, and nitrate nitrogen. Study completed in 1966.
Water-Phenols	Phenol and 2,4-dichlorophenol in water by two specified methods. Study completed in 1966.

Air-Inorganics	Chloride, sulfate, fluoride, and nitrate in aqueous solution and on glass-fiber high-volume filter mats. Study completed in 1958.
Air-Lead	Filter paper tape impregnated with lead. Study completed in 1961.
Air-Particulates	Microscopic identification of some common atmospheric particulates. Study completed in 1964.
Air-Sulfur Dioxide	Sulfur dioxide in air by a specified method. Study completed in 1963.
Water-Pesticides	Lindane, heptachlor epoxide, DDE, and dieldrin in water. Study completed in 1965.
Food-Pesticides	DDT in milk. Study completed in 1962. Lindane, heptachlor epoxide, DDE, and dieldrin in food. Study completed in 1965.

PARTICIPANTS IN THIS STUDY

Alabama State Department of Public Health, Montgomery
American Cyanamid Company, Bound Brook, New Jersey
American Oil Company, Whiting, Indiana
Armco Steel Corporation, Middletown, Ohio
Atomic Energy Research Establishment, Harwell, Berks, England
Bio-Technics Laboratories, Incorporated, Los Angeles, California
British Coke Research Association, Chesterfield, Derbyshire, England
Brown and Caldwell Laboratories, San Francisco, California
Calgon Corporation, Pittsburgh, Pennsylvania
California State Department of Public Health, Berkeley
California State Department of Public Health, Los Angeles
California State Department of Water Resources, Sacramento
California Water Service Company, San Jose
Central Water Filtration Plant, Chicago, Illinois
Chrysler Corporation, Detroit, Michigan
City's Institute for Health Protection, Beograd, Yugoslavia
Colorado State Department of Public Health, Denver
Delaware Water and Air Resource Commission, Dover
Department of Mines and Technical Surveys, Ottawa, Ontario, Canada
Department of Municipal Laboratories, Hamilton, Ontario, Canada
Department of National Health and Welfare, Ottawa, Ontario, Canada
Department of National Health and Welfare, Vancouver, Canada
Environmental Laboratory (SGHK), Kelly AFB, Texas
Erie County Department of Health, Buffalo, New York
Flint Water Plant, Michigan
Fourth US Army Medical Laboratory, Fort Sam Houston, Texas
Fresno Department of Public Health, California
Havens-Emerson, Oradell, New Jersey
Idaho Department of Health, Boise
Indiana State Board of Health, Indianapolis
INFILCO, Division of Fuller Company, Tucson, Arizona
Iowa State Hygienic Laboratory, Des Moines
Kentucky State Department of Health, Frankfort
Lawrence Experiment Station, Massachusetts
Louisiana State Board of Health, New Orleans
Louisiana State University, Baton Rouge
Los Angeles County Flood Control District, California
Los Angeles Department of Public Works, Hyperion Treatment Plant, Playa Del Rey, California
Los Angeles Department of Water and Power, California
Metropolitan Corporation of Greater Winnipeg, Manitoba, Canada
Metropolitan Utilities District, Omaha, Nebraska
Michigan Department of Health, Lansing
Minneapolis Water Department, Minnesota

Monroe County Health Department Laboratory, Rochester, New York
Monsanto Company, St. Louis, Missouri
Montana State Board of Health, Helena
New Jersey State Department of Health, Trenton
New York City Department of Health, New York
New York State Conservation Department, Scottsville
New York State Department of Health, Albany
North Carolina Department of Water Resources, Raleigh
North Jersey District Water Supply Commission, Wanaque, New Jersey
Ohio Department of Health, Columbus
Ontario Water Resources Commission, Toronto, Ontario, Canada
Orange County Air Pollution Control District, Anaheim, California
Oregon State Board of Health, Portland
Pan American World Airways, Patrick AFB, Florida
Pennsylvania Department of Health, Harrisburg
Ray W. Hawksley Company, Incorporated, Richmond, California
Regional Environmental Health Laboratory (LSGHM), McClellan AFB, California
Sandia Corporation, Albuquerque, New Mexico
Sixth US Army Medical Laboratory, Fort Baker, Sausalito, California
Tennessee Stream Pollution Control Board, Nashville
Texas State Department of Health, Austin
USDI, FWPCA, Great Lakes-Illinois River Basins Project, Chicago, Illinois
USDI, FWPCA, Hudson Champlain Project, Metuchen, New Jersey
USDI, FWPCA, Lawrence, Massachusetts
USDI, FWPCA, Ohio River Basin Project, Wheeling, West Virginia
USDI, FWPCA, Pacific Northwest Water Laboratory, Corvallis, Oregon
USDI, FWPCA, Southeastern Comprehensive Water Pollution Control Project, Atlanta, Georgia
USDI, FWPCA, Water Quality Activities, Cincinnati, Ohio
USDI, Geological Survey, Columbus, Ohio
USDI, Geological Survey, Little Rock, Arkansas
University of California, Richmond
University of Leeds, England
Vermont Department of Water Resources, Montpelier
Washington State University, Pullman
Water Research Association, Marlow, Bucks, England

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ABSTRACT

This study consisted of four concentrated solutions shipped in sealed glass ampoules. The participants were instructed on receipt to dilute 5 ml of each sample to 1 liter with a good quality (phenol free) distilled water, and were informed that the samples would then contain concentrations of phenol and 2, 4-dichlorophenol in the range of 1.0 to 200 µg per liter. The results of this study indicate that neither of the two Standard Methods studied will measure very accurately or precisely the total phenolic content of a water sample. The distillation and chloroform extraction (of the final color) method will measure the phenol content of a sample very accurately and precisely, but it is not as sensitive as is desired. On the other hand, the simplified aminoantipyrine method will measure neither phenol nor 2, 4-dichlorophenol very accurately or precisely. Some modifications are suggested, which presumably would improve the latter method.

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WATER PHENOLS NO. 1

PURPOSE OF THE STUDY

The occurrence of phenol in water supplies is usually due to waste discharges from gas works, coke ovens, oil refineries, chemical plants and from humans and animals. Phenol concentrations in excess of 2.0 µg/l in chlorinated domestic water supplies can cause taste and odor problems; in river waters concentrations in excess of 200 µg/l can have damaging or fatal effects on fish and aquatic life. At present, the 12th edition of Standard Methods for the Examination of Water and Wastewater offers three methods for the analysis of phenols, but the precision and accuracy of none of these have been determined.

The objective of this study, therefore, was to evaluate the ability of methods A and C to quantitatively measure a low concentration of a mixture of phenols. Method B was not included since it is designed to measure only high phenol concentrations.

DESIGN OF THE STUDY

To reduce shipping costs and to obtain greater stability, the samples were prepared as concentrated solutions and shipped in sterile, sealed 25-ml glass ampoules. When the participant diluted 5 ml of each sample to 1 liter, with distilled water, the samples contained the amounts of phenols indicated in Table 1. To ensure stability, the concentrates contained 1.0 gram of copper sulfate per liter to prevent biochemical oxidation and sufficient phosphoric acid to lower the pH to 2.0.

Table 1. Composition of Samples

Sample No.	Phenol, µg/l	2,4-Dichlorophenol µg/l
1	2.0	0.0
2	50.0	0.0
3	0.0	100.0
4	50.0	100.0

So that each analyst would follow exactly the prescribed procedure, permission was obtained from the American Public Health Association to copy the procedures .rom Standard Methods. Copies were sent with the samples to each participant. These procedures were verbatim, except that in method C, 2, 4-dichlorophenol standards were substituted for phenol standards. This was done because preliminary correspondence with Michael J. Taras, Chairman of the Joint Editorial Board, and Samuel D. Faust, a member of the subcommittee, indicated that phenol standards were unsatisfactory and that 2, 4-dichlorophenol standards were originally intended. It was assumed that none of the participants would have available a supply of 2, 4-dichlorophenol, so about 0.3 gram of 2, 4-dichlorophenol crystals was sent with the samples for use by the participants as standards.

Each participant was requested to do a single analysis for phenols on each of the four samples by each of the provided (two) methods. They were also instructed to store the samples in the refrigerator in a closed container if all of the samples could not be analyzed by both methods immediately after dilution of the concentrates.

TREATMENT OF THE DATA

Upon receipt of the results of analysis from the participants, the data were reviewed and coded for transfer to IBM punch cards. The data were then key-punched and analyzed by electronic computer for normality of distribution and rejection of outliers.

The previously used technique of plotting the data on probability paper to determine outliers was also used to verify the computer programming. The data were then statistically analyzed by computer for precision and accuracy.

Bar graphs are included with the text to provide a pictorial display of the data; rejected values are indicated by broken bars.

Analytical results received by the Analytical Reference Service after statistical analysis was begun (2 months after shipment of the sample) were not included in this report.

RESULTS

Sample 1

Sample 1 was designed to contain 2.0 µg of phenol per liter of water. Seventy-three laboratories analyzed this sample by method 1 (see Figure 1), the standard method of distillation with chloroform extraction of the final color. [1] Eight of the results were rejected as outliers. As indicated in Table 2, the mean of the retained results was 2.9 µg per liter, with a relative error of 45.2 percent and a relativ standard deviation of 81.3 percent. These results indicate (see also results on sample 2) that this method is capable of measuring phenol with reasonable accuracy and precision, but that the concentration of phenol in this sample is near the limit of the sensitivity of the method.

Sixty-six laboratories analyzed this sample by method 2 (see Figure 2), the simplified aminoantipyrine standard method, [2] and, as with method 1, eight laboratory results were rejected as outliers. By this method, the mean of the retained results was 5.0 µg per liter with a relative error of 150 percent and a relative standard deviation of 134 percent. These results indicate that this method is not capable of measuring phenol (see also results for sample 2) with any degree of precision or accuracy.

Table 2. Summary of Statistical Data for Sample 1

(Amount added = 2.0 µg of phenol per liter)

	Method 1	Method 2*
Number of results included	65	58
Number of outliers	8	8
Mean, µg/l	2.9	5.0
Mean error, µg/l	+0.9	+3.0
Relative error, %	45.2	150.0
Standard deviation, µg/l	2.36	6.72
Relative standard deviation, %	81.3	134.0
Tolerance limits, µg/l	5.5	------

* Data are nonnormal.

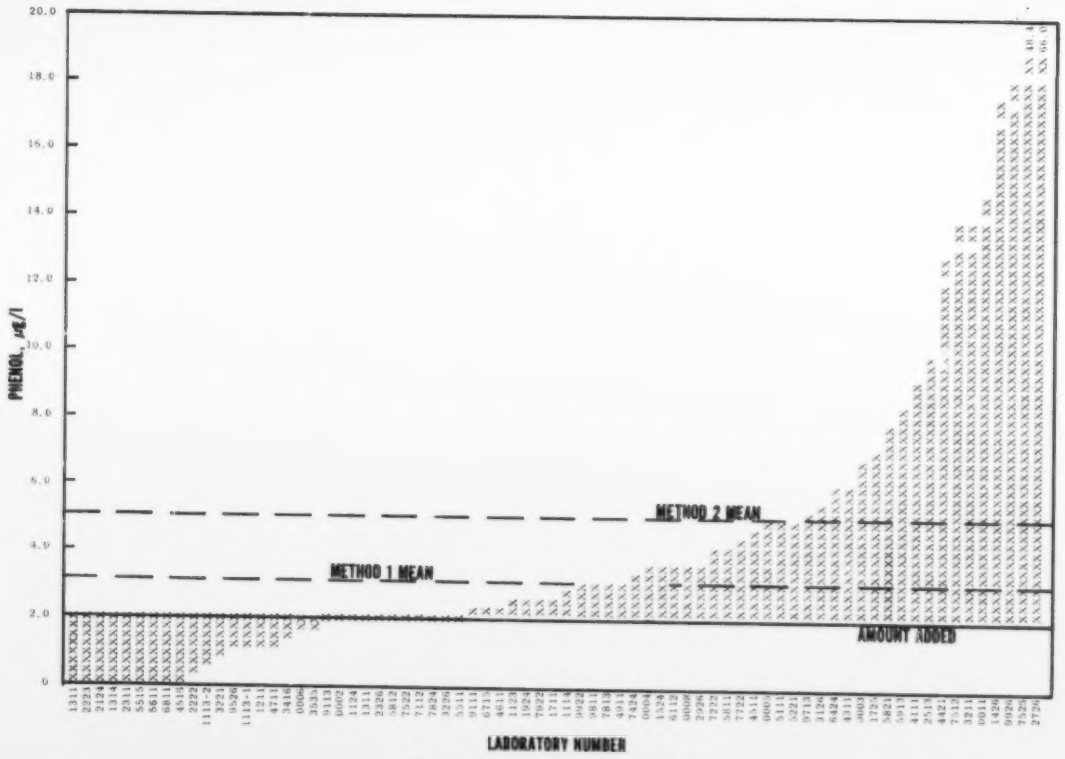

Figure 1. Bar graph for sample 1 by method 1.

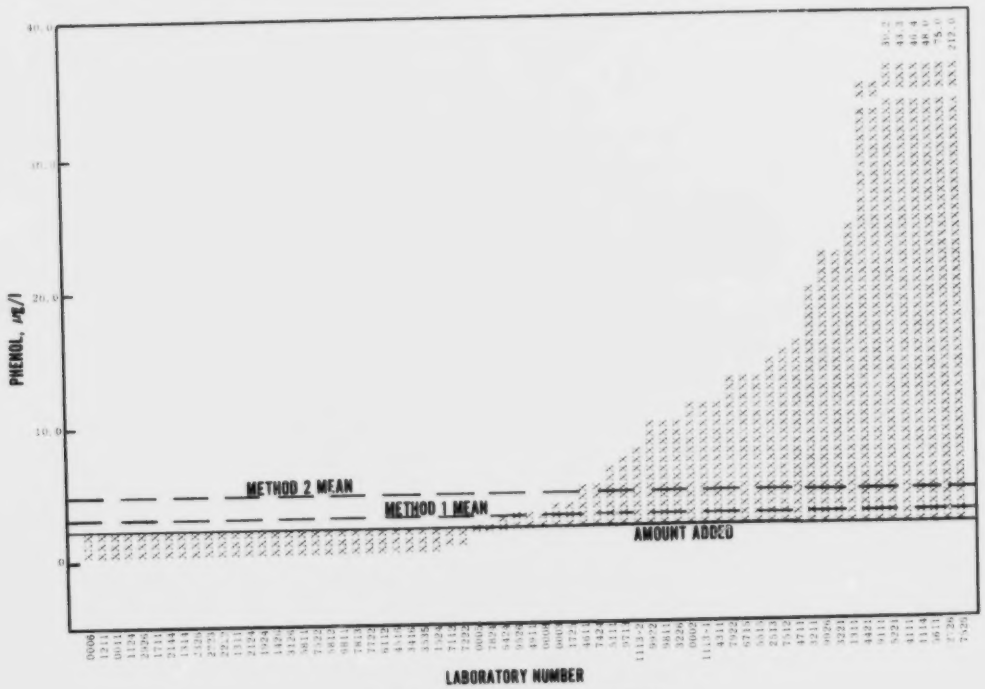

Figure 2. Bar graph for sample 1 by method 2.

Sample 2

Sample 2 was designed to contain 50 µg of phenol per liter of water. Seventy-five laboratories analyzed this sample by method 1 [1] (see Figure 3) and six of the results were rejected as outliers. As indicated in Table 3, the mean of the retained results was 46.4 µg per liter, with a relative error of 7.2 percent and a relative standard deviation of 20.8 percent. Thus, this method will measure phenol at this concentration with reasonably good precision and accuracy.

Sixty-eight laboratories analyzed this sample by method 2 [2] (see Figure 4), and one result was rejected as an outlier. By this method, the mean of the retained results was 24.5 with a relative error of 51.0 percent and a relative standard deviation of 113 percent. Thus, these results indicate that this method is not capable of measuring phenol with any degree of precision and accuracy.

Table 3. Summary of Statistical Data for Sample 2

(Amount added = 50 µg of phenol per liter)

	Method 1	Method 2*
Number of results included	69	67
Number of outliers	6	1
Mean, µg/l	46.4	24.5
Mean error, µg/l	-3.6	-25.5
Relative error, %	7.2	51.0
Standard deviation, µg/l	9.65	27.71
Relative standard deviation, %	20.8	113.0
Tolerance limits, µg/l	22.2	-----

* Data are nonnormal

Sample 3

Sample 3 was designed to contain 100 µg of 2,4-dichlorophenol per liter. Seventy-six laboratories analyzed this sample by method 1 [1] (see Figure 5), and eight of the results were rejected as outliers. As indicated in Table 4, the mean of the retained results was 17.4, with a relative error of 82.6 percent and a relative standard deviation of 47.8 percent. Thus, this method is not capable of measuring 2,4-dichlorophenol with any degree of precision and accuracy.

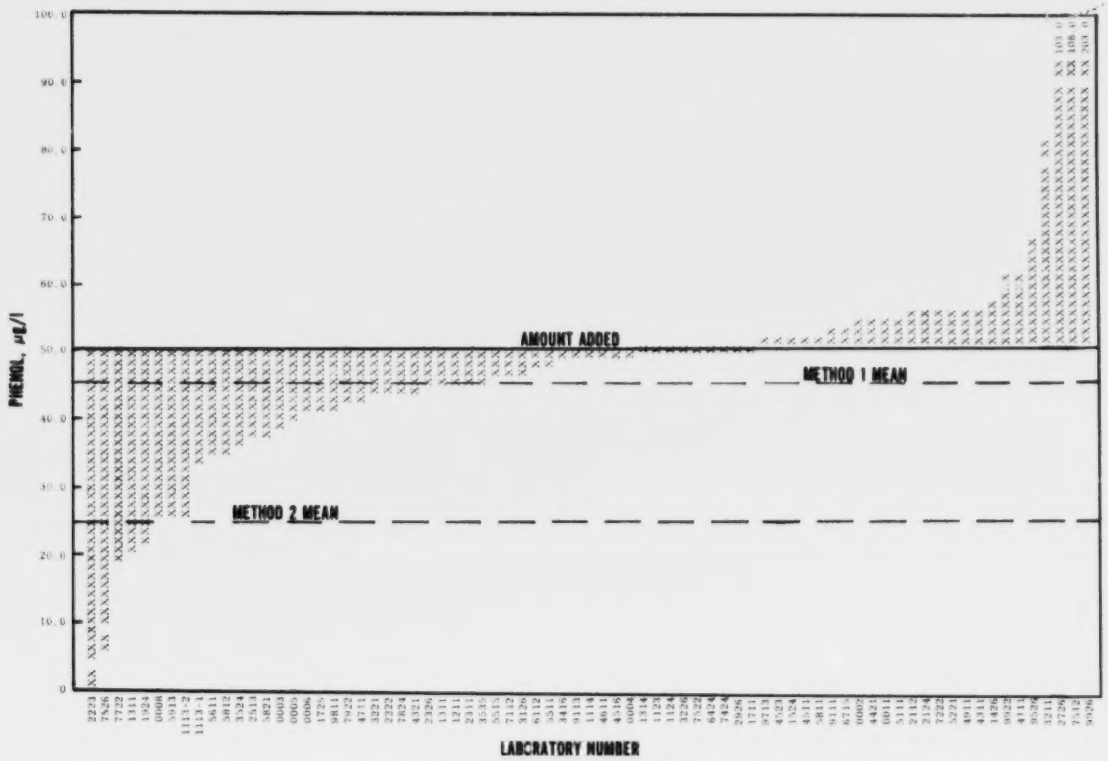

Figure 3. Bar graph for sample 2 by method 1.

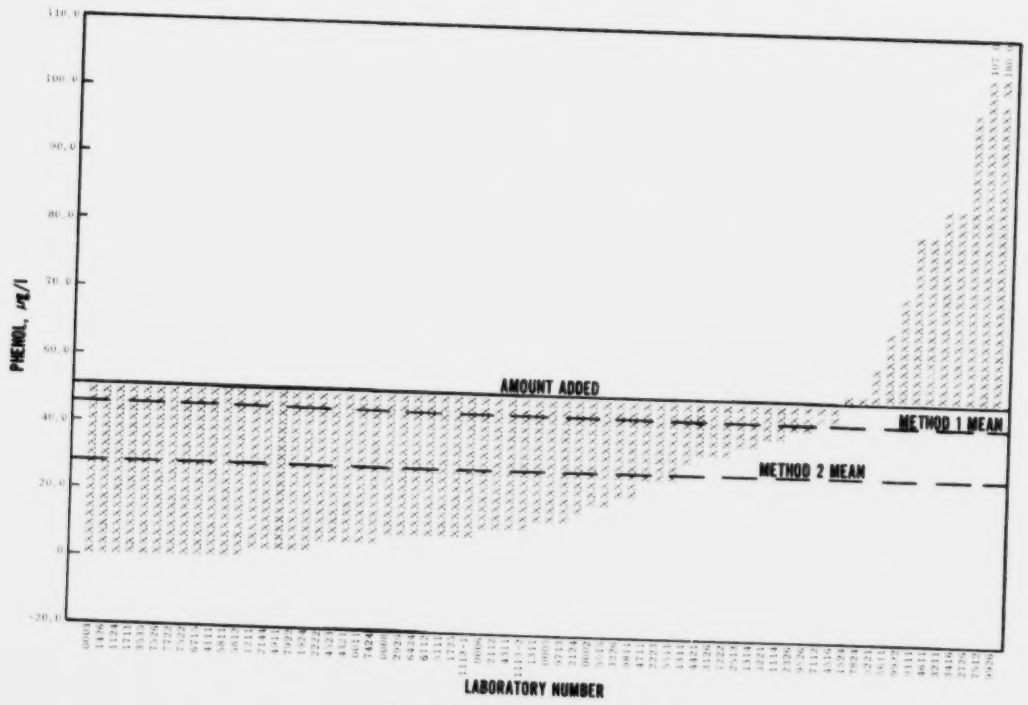

Figure 4. Bar graph for sample 2 by method 2.

Seventy-one laboratories analyzed this sample by method 2 (see Figure 6), and one result was rejected as an outlier. By this method the mean of the retained results was 88.8 with a relative error of 11.2 percent and a relative standard deviation of 32.1 percent. Thus, this method is capable of measuring 2,4-dichlorophenol with a reasonable degree of accuracy, but with only fair precision.

Table 4. Summary of Statistical Data for Sample 3

(Amount added = 100 µg of 2,4-dichlorophenol per liter)

	Method 1	Method 2
Number of results included	68	70
Number of outliers	8	1
Mean, µg/l	17.4	88.8
Mean error, µg/l	-82.6	-11.2
Relative error, %	82.6	11.2
Standard deviation, µg/l	8.34	28.47
Relative standard deviation, %	47.8	32.1
Tolerance limits, µg/l	19.2	65.4

Sample 4

Sample 4 was designed to contain 50 µg of phenol and 100 µg of 2,4-dichlorophenol per liter, or in other words, 150 µg of phenols per liter. Seventy-three laboratories analyzed this sample by method 1(1) (see Figure 7) and one result was rejected as an outlier. As indicated in Table 5, the mean of the retained results was 67.7, with a relative error of 54.8 percent and a relative standard deviation of 26.2 percent. Thus, this method is not capable of measuring the total phenolic content of a sample with a reasonable degree of precision and accuracy.

Sixty-seven laboratories analyzed this sample by method 2(2) (see Figure 8) and two results were rejected as outliers. By this method the mean of the retained results was 96.4 µg per liter, with a relative error of 35.7 percent and a relative standard deviation of 31.4 percent. Thus, this method also is not capable of measuring the total phenolic content of a sample with any reasonable degree of precision and accuracy.

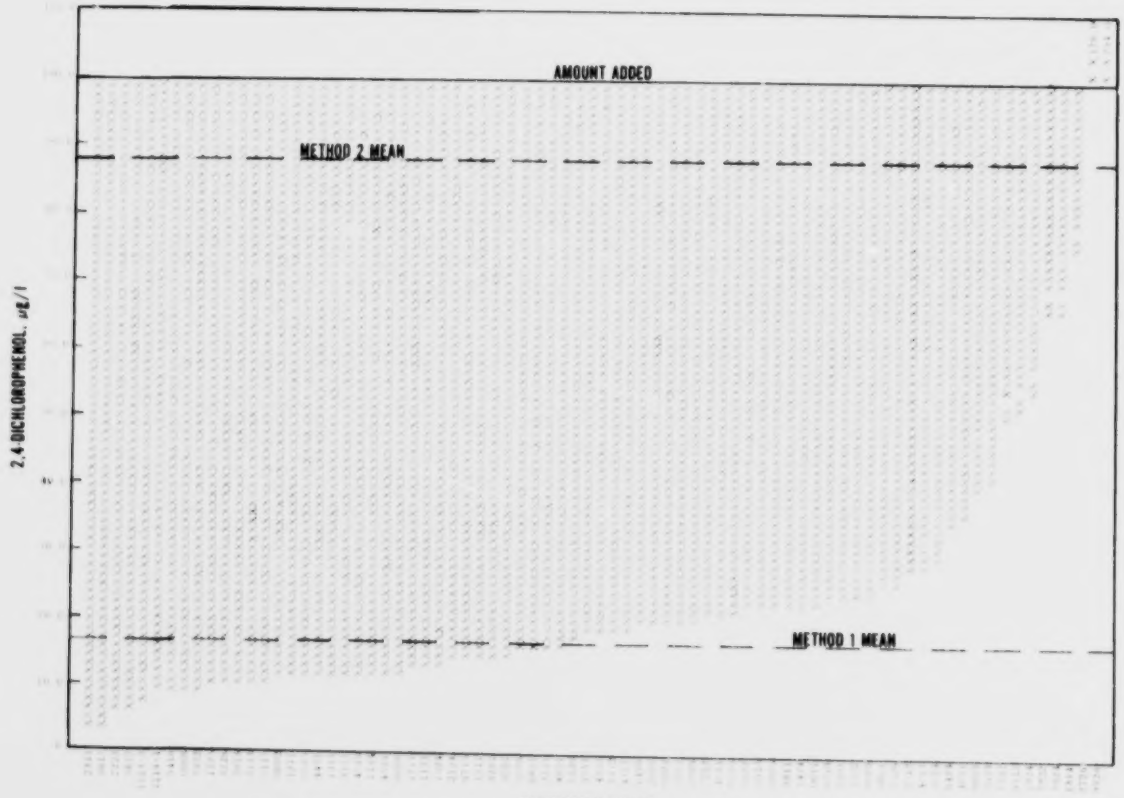

Figure 5. Bar graph for sample 3 by method 1.

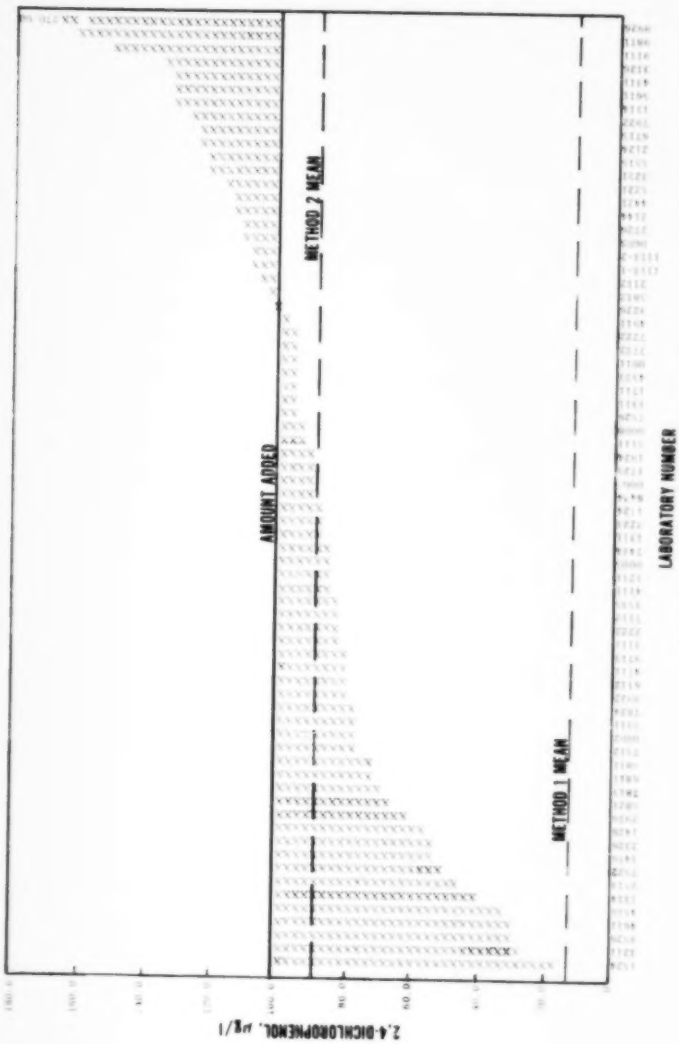

Figure 6. Bar graph for sample 3 by method 2.

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Table 5. Summary of Statistical Data for Sample 4

(Amount added = 50 µg of phenol and 100 µg of 2, 4-dichlorophenol per liter)

	Method 1	Method 2
Number of results included	72	65
Number of outliers	1	2
Mean, µg/l	67.7	96.4
Mean error, µg/l	-82.3	-53.6
Relative error, %	54.8	35.7
Standard deviation, µg/l	17.71	30.29
Relative standard deviation, %	26.2	31.4
Tolerance limits, µg/l	40.6	70.1

DISCUSSION

Samples 1 and 2 contained 2.0 µg and 50 µg of phenol, respectively, per liter; as expected, by method 1 most of the participants found approximately these quantities. By method 2, however, it was not expected that the participants would find any phenol since petroleum ether does not extract phenol from an aqueous solution (at least not under the conditions of this test).

If by chance a little phenol was carried through the extraction, it is conceivable that some color would be obtained in samples 1 and 2 by method 2, because under the conditions of this test (pH 7.9 rather than 10.0) phenol gives slightly more color than does the same amount of dichlorophenol. This apparently is not the explanation, however, because sample 2, which contained the greatest quantity of phenol, gave the lowest result (in comparison to the known amount present). The explanation for any color in samples 1 and 2 by method 2 seems, rather, to be due to two other possible causes. First, ARS found, as did some of the participants, that the petroleum ether in some cases contained a considerable amount of a substance which was extractable from the petroleum ether with 0.5 normal ammonium hydroxide and which reacted with aminoantipyrine to produce a color under the conditions of the test. Secondly, ARS found that when a series of solutions of decreasing pH (containing no dichlorophenol) was treated with 4 amino-antipyrine and potassium ferricyanide, the color increased from an absorbancy of 0.04 at a pH of 7.9 to 0.70 at a pH of 7.35. Furthermore, at a pH of 7.4 a fine turbidity began to develop, which undoubtedly

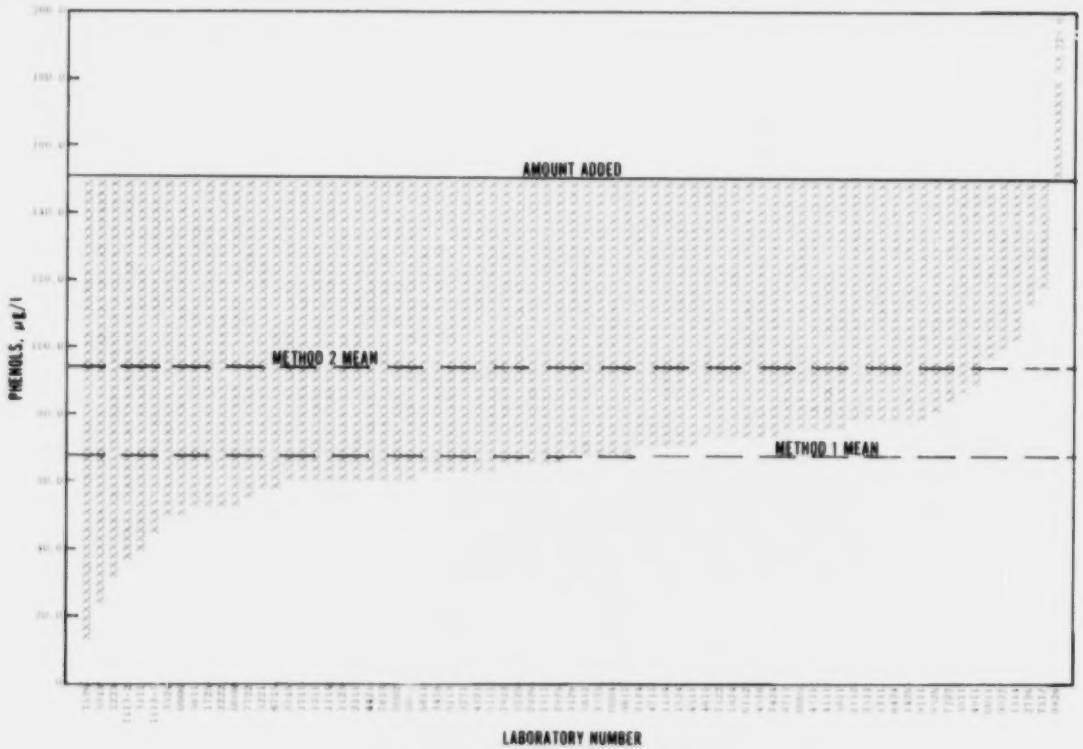

Figure 7. Bar graph for sample 4 by method 1.

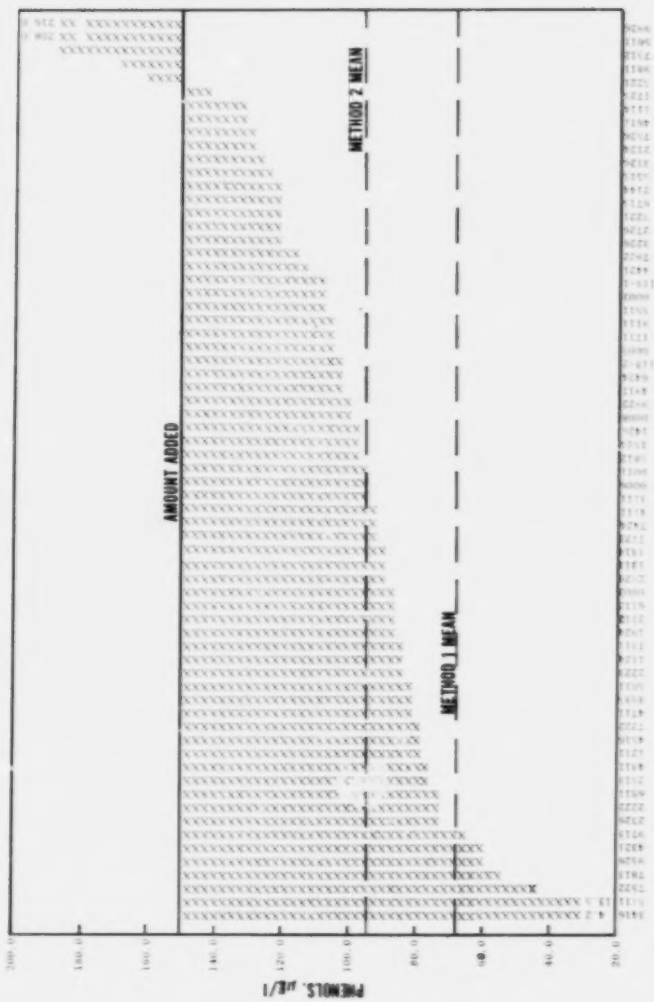

Figure 8. Bar graph for sample 4 by method 2.

contributed to the absorbance. This turbidity due to low pH may also explain the difficulty some participants had with this method.

Sample 3 contained 100 µg of 2, 4-dichlorophenol per liter. It was expected that by method 1 the participants would find about 10 µg of phenol per liter, since under the conditions of this test 2, 4-dichlorophenol only gives about one-tenth the amount of color as the same amount of phenol. By method 2, the participants should have found 100 µg of 2, 4-dichlorophenol per liter. They did not find this amount apparently because (as determined by ARS) 2, 4-dichlorophenol is not extracted quantitatively with petroleum ether. If the method had specified, as was suggested by a few participants, that the standards be carried through the extraction procedure, this fallacy would presumably (as was verified by ARS) have been rectified.

Sample 4 contained 50 µg of phenol and 100 µg of 2, 4-dichlorophenol. Therefore, the results obtained on sample 4, by either method, should have been the sum of the results obtained on samples 2 and 3 by the same method; namely, 10 plus 50 or 60 µg per liter by method 1, and 0 plus 100 or 100 µg by method 2. Table 5 shows that these were approximately the results obtained, but neither method gave very precise or accurate results because neither method is capable of measuring the total amount of phenolic substances present.

COMMENTS OF THE PARTICIPANTS

The most frequent comment was that the simplified aminoantipyrine method was unsatisfactory because turbidity developed in both reagent blanks and standards.

The next most frequent comment was that the pH was other than 7.9. Some found the pH after ammonia extraction and addition of phosphate buffer to be as low as 7.4, and others, as high as 8.8.

The third most frequent comment was that the simplified aminoantipyrine extraction procedure was physically exhausting; the method took more time, space, and glassware, and could hardly be considered an improvement over the distillation technique.

Another frequent comment was that in the simplified aminoantipyrine method the standards must be treated exactly as the samples. If the calibration curve is not prepared by extracting the standards in exactly the same way as are the samples, the absorbance of the samples cannot be correlated with the absorbance of the standards.

Two laboratories commented that petroleum ether extraction gives very low recoveries with phenol itself, and thus the method is extremely misleading.

It was also noted that the 2,4-dichlorophenol complex with aminoantipyrine and potassium ferricyanide fades rapidly after the 15-minute development period. One laboratory stated that no coloration was produced unless the potassium ferricyanide solution was at least 20 hours old.

It was reported that some reagent grade petroleum ethers apparently contain traces of phenol or substances that react with aminoantipyrine at the microgram level as high blanks were frequently encountered. On the other hand, it is possible that high blanks are due to poorly controlled pH; since concentrated ammonium hydroxide is very volatile, the concentration will vary from one reagent bottle to another and this will affect both the pH and intensity of color in the standards and samples. Greater precision could be achieved if the ammonium hydroxide was standardized after preparation.

One laboratory commented that their experience with the simplified aminoantipyrine method indicated a variable negative error in the ammonium hydroxide extraction procedure, which could be corrected by the addition of a few milligrams of sodium hydroxide.

Three laboratories commented about the distillation and chloroform extraction procedure, but only one of these was adverse; namely, that the reaction of aminoantipyrine and phenol at pH 10.0 yields a color compound with about six times the optical density of that produced with 2,4-dichlorophenol under the same conditions. This obviously means that the choice of method is critical in defining the results obtained in the analysis of given samples of water or wastes. They believed the most inclusive procedure for "phenols" may be the most meaningful in terms of assessing water quality.

SUMMARY AND CONCLUSIONS

The results of this study indicate that neither of the methods studied will measure very accurately or precisely the total phenolic content of a water sample. Method 1 (distillation plus chloroform extraction) will measure accurately and precisely the phenol content of a water sample if no other phenolic compounds are present; the sensitivity of this method, however, is not as good as it should be, namely, at a concentration of 2.0 µg per liter the relative error and relative standard deviation are respectively only 45.2 and 81.3 percent.

Method 2 (simplified aminoantipyrine), on the other hand, measures neither phenol nor 2, 4-dichlorophenol very accurately or precisely, primarily because of fallacies in the technique. The method could, presumably, be improved so that it would measure 2, 4-dichlorophenol accurately and precisely by specifying that (1) the 2, 4-dichlorophenol standards be carried through the extraction procedure; (2) the petroleum ether be prepurified by extraction with ammonia hydroxide; and (3) the pH be checked and adjusted, if necessary, to pH 7.9 after adding phosphate buffer. This method can hardly be classified as a simplified procedure, however, for most participants felt it was more difficult and time consuming than the distillation and chloroform extraction procedure.

Either method will give low results for a sample containing mixed phenols, the degree of error depending on the specific phenols present.

REFERENCES

1. Distillation and Chloroform Extraction Method. Standard Methods for the Examination of Water and Wastewater. pp. 229 and 517-9. 12th edition. APHA, AWWA, WPCF. New York, 1965.

2. Simplified Aminoantipyrine Method. Standard Methods for the Examination of Water and Wastewater. pp. 521-3. 12th edition. APHA, AWWA, WPCF. New York, 1965.

3. Gibbs Method. Standard Methods for the Examination of Water and Wastewater. pp. 409-11. 11th edition. APHA, AWWA, WPCF. New York, 1960.

4. Modified Simplified Aminoantipyrine Method. Method 2 (Reference 2 above) was modified by adjusting the pH of the extracted reagent blanks and samples to pH 7.9 before adding aminoantipyrine and potassium ferricyanide.

5. Modified Simplified Aminoantipyrine Method. Method 2 (Reference 2 above) modified by using petroleum ether extracted standards.

6. Modified Simplified Aminoantipyrine Method. Method 2 (Reference 2 above) modified by adjusting the pH to 8.4 in order to obtain clear solutions.

7. Modified Distillation and Chloroform Extraction Method. Method 1 (Reference 1 above) modified by using 3 percent aminoantipyrine solution rather than 2 percent.

8. Modified Simplified Aminoantipyrine Method. Method 2 (Reference 2 above) modified by using 2 percent potassium ferricyanide solution rather than 8 percent.

9. Modified Distillation and Chloroform Extraction Method. Method 1 (Reference 1 above) modified by eliminating distillation and using one-eighth the concentration of potassium ferricyanide and one-twelfth the amount of aminoantipyrine at pH 8.2.

10. Direct Photometric. Standard Methods for the Examination of Water and Wastewater. pp. 520-21. 12th edition. APHA, AWWA, WPCF. New York, 1965.

11. Method D:30a-2, Aminoantipyrine. Geological Survey Water-Supply Paper.

12. Direct photometric method (Reference 10 above) using a Technicon Autoanalyzer equipped with a steam distillation unit.

13. Water and Sewage Analysis Procedure, Catalog No. 9. p. 34. Hach Chemical Company. Ames, Iowa, 1963.

APPENDICES

APPENDIX A.

TABULATION OF RESULTS

Table A-1. SAMPLE 1, PHENOL (2.0 µg/l)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
0002	2.0	11.0		
0003	6.8	4.0		
0004	3.5	---	11.0	4
0005	5.0	2.0	2.0	12
0006	1.6	0.0		
0008	3.6	3.2		
0011	14.6	0.0		
1113-1	1.0	11.0		
1113-2	0.4	7.8		
1114	2.8	46.4		
1123	2.5	---	25.1	6
1124	2.0	0.0	2.0	3
1211	1.0	0.0		
1311-1	2.0	24.0		
1311-2	0.0	---		
1311-3	---	0.0		
1314	0.0	0.0		
1426	17.5	0.0		
1524	3.5	0.2		
1711	2.6	0.0		
1725	7.0	4.0		
1924	2.5	0.0		
2124	0.0	0.0		
2144	---	0.0		

(Table A-1 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
2222	0.1	0.0		
2223	0.0	0.0	0.0	11
2311	0.0	---	0.0	5
2326	2.0	0.0		
2513	10.0	14.0		
2726	66.0	75.0		
2926	3.6	0.0		
3126	5.4	0.0		
3211	14.0	20.0		
3221	0.8	22.0		
3226	2.0	10.0		
3416	1.1	0.0		
3535	1.7	0.0		
4111	9.0	43.3		
4311	6.0	11.2		
4421	12.8	35.0		
4511	4.9	---	5.0	10
4516	0.0	0.0		
4611	2.4	4.6		
4711	1.0	16.0		
4911	3.0	3.0		
5111	5.0	6.2		
5221	5.0	39.2		
5511	2.0	---		
5515	0.0	12.5		
5611	0.0	48.0		
5811	4.0	0.0		

(Table A-1 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
5812	2.0	0.0		
5821	8.0	---		
5913	8.5	---		
6112	3.5	0.0		
6424	6.0	2.6	3.5	9
6715	2.4	12.5		
6811	0.0	0.0		
7112	2.0	1.0		
7222	4.0	1.2		
7424	3.2	4.8		
7512	14.0	15.0		
7522	2.0	0.0		
7526	48.4	212.0		
7722	4.4	0.0		
7813	3.0	0.0		
7824	2.0	2.0		
7922	2.5	12.5		
8512-2	---	---	0.0	7
8512-3	---	---	0.0	7
8512-3	---	---	0.0	8
9111	2.3	35.2		
9113	2.0	---		
9526	1.0	3.0		
9713	5.2	7.0		
9811	3.0	10.0		
9922	3.0	10.0		
9926	18.0	22.0	10.0	13

Table A-2. SAMPLE 2, PHENOL (50.0 µg/l)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
0002	54.0	18.0		
0003	39.0	0.0		
0004	49.7	---	9.0	4
0005	40.0	13.0	51.8	12
0006	41.0	10.0		
0008	25.0	6.5		
0011	54.6	5.1		
1113-1	33.0	8.0		
1113-2	25.4	12.8		
1114	49.1	42.0		
1123	50.0	----	22.8	6
1124	50.0	0.0	50.0	3
1211	46.0	2.0		
1311-1	46.0	31.0		
1311-2	20.5	----		
1311-3	----	13.0		
1314	50.0	36.0		
1426	58.0	0.0		
1524	52.5	52.0		
1711	50.4	0.0		
1725	42.0	7.0		
1924	22.4	3.8		
2112	55.0	11.0		
2124	55.0	16.0		
2144	----	2.0		
2222	44.0	4.0		
2223	0.0	25.0	20.0	11

(Table A-2 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
2311	46.0	----	0.0	5
2326	45.0	44.0		
2513	38.0	35.0		
2726	103.0	98.0		
2926	50.4	6.5		
3126	48.4	34.0		
3211	80.0	86.0		
3221	44.0	40.0		
3226	50.0	20.0		
3416	48.9	86.5		
3524	37.2	----		
3535	46.0	0.0		
4111	61.0	0.0		
4311	56.0	11.2		
4321	44.0	4.0		
4425	54.4	33.0		
4511	52.5	----	52.0	10
4516	49.2	16.0		
4523	52.0	4.0		
4611	49.1	82.4		
4711	43.0	24.0		
4911	56.0	3.0		
5111	54.8	6.9		
5221	55.8	60.8		
5511	48.5	25.0		
5515	47.0	18.3		
5611	35.0	64.0		

(Table A-2 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
5811	52.5	0.0		
5812	36.0	0.0		
5821	38.0	---		
5913	25.0	---		
6112	48.5	6.5		
6424	50.5	6.5	51.0	9
6715	53.2	0.0		
7112	48.0	46.0		
7222	55.2	34.8		
7424	50.2	5.2		
7512	108.0	107.0		
7522	50.0	0.0		
7526	5.8	0.0		
7722	19.4	0.0		
7824	44.0	52.0		
7922	42.5	3.5		
8512-1	----	----	212.0	7
8512-1	----	----	0.0	8
8512-3	----	----	55.0	7
8512-5	----	----	0.0	8
9111	53.2	81.0		
9113	49.0	----		
9526	66.4	45.0		
9713	52.0	14.0		
9811	42.0	20.0		
9922	60.0	70.0		
9926	203.0	180.0	280.0	13

Table A-3. SAMPLE 3, 2,4-DICHLOROPHENOL (100 µg/l)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
0002	11.0	78.0		
0003	40.8	109.0		
0004	25.6	----	72.0	4
0005	23.0	87.0	6.1	12
0006	9.0	90.0		
0008	12.4	92.6		
0011	23.3	94.2		
1113-1	8.0	108.0		
1113-2	6.8	108.0		
1114	12.2	129.6		
1123	13.0	----	52.4	6
1124	29.5	88.3	20.0	3
1211	11.0	87.0		
1311-1	15.0	94.0		
1311-2	12.0	----		
1311-3	----	88.0		
1314	75.9	40.0		
1426	20.0	54.0		
1524	13.0	19.2		
1711	12.5	94.0		
1924	54.2	91.5		
2112	28.0	105.0		
2124	14.0	122.0		
2144	----	113.0		
2222	67.0	84.0		
2223	4.0	88.0	53.0	11
2311	2.5	----	76.0	5

(Table A-3 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
2326	20.0	52.0		
2513	42.0	45.0		
2726	128.0	111.0		
2926	20.8	61.0		
3111	12.9	83.0		
3126	17.6	136.0		
3211	18.0	30.0		
3221	15.0	120.0		
3226	10.0	100.0		
3416	8.9	52.0		
3535	21.6	84.6		
4111	18.7	86.7		
4311	18.0	132.0		
4421	11.6	113.0		
4511	21.2	----	40.0	10
4516	12.0	35.5		
4523	12.2	94.0		
4611	17.5	34.4		
4711	28.0	80.0		
4911	36.0	97.0		
5111	10.5	92.4		
5221	15.0	116.0		
5511	20.5	78.2		
5515	11.0	121.2		
5611	2.5	130.0		
5811	26.0	75.5		
5812	4.4	104.0		

(Table A-3 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
5821	24.0	68.0		
5913	22.0	----		
6112	52.5	80.0		
6424	34.0	89.8		
6715	14.6	123.0		
6811	17.0	74.2		
7112	18.5	84.0		
7222	21.0	95.6		
7424	23.2	87.2		
7512	50.0	78.0		
7522	22.0	50.5		
7526	26.8	94.0		
7722	24.4	94.4		
7813	10.0	70.0		
7824	67.0	79.0		
7922	9.6	124.0		
8512-1	----	----	19.0	7
8512-1	----	----	24.0	8
8512-2	----	----	27.0	7
8512-2	----	----	76.0	8
8512-3	----	----	18.0	7
9111	17.3	150.4		
9113	10.0	----		
9526	17.0	34.2		
9713	24.0	81.0		
9811	23.0	160.0		
9922	20.0	80.0		
9926	294.0	270.0	316.0	13

Table A-4. SAMPLE 4, PHENOL (50.0 µg/l) + 2,4-DICHLOROPHENOL (100 µg/l)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
0002	61.0	87.0		
0003	61.0	108.0		
0004	69.3	----	88.0	4
0005	76.0	105.0	56.5	12
0006	52.0	96.0		
0008	55.2	99.4		
0011	97.7	96.2		
1113-1	44.0	108.0		
1113-2	36.0	104.8		
1114	60.5	129.6		
1123	60.5	----	89.7	6
1124	73.0	82.5	60.0	3
1211	60.0	77.0		
1311-1	66.0	84.0		
1311-2	78.0	----		
1311-3	----	88.0		
1314	104.0	88.0		
1426	79.0	98.0		
1524	73.0	97.8		
1711	59.3	106.0		
1725	54.0	144.0		
1924	75.0	85.7		
2112	78.0	86.0		
2124	72.0	127.0		
2144	----	121.0		
2222	55.0	72.0		
2223	30.0	82.0	37.0	11

(Table A-4 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
2311	60.5	----	80.0	5
2326	66.0	72.0		
2513	78.0	76.0		
2726	117.0	120.0		
2926	67.2	87.5		
3111	39.5	96.0		
3126	67.6	126.0		
3221	64.0	120.0		
3416	62.2	4.2		
3524	51.0	----		
3535	68.4	80.5		
4111	76.2	93.3		
4311	76.0	76.0		
4321	64.0	60.0		
4421	60.8	113.0		
4511	73.1	----	111.0	10
4516	75.8	78.0		
4611	74.0	128.8		
4711	72.0	80.0		
4911	89.0	103.0		
5111	64.1	13.5		
5221	58.6	160.8		
5511	87.5	107.5		
5515	59.0	123.0		
5611	53.0	208.0		
5811	77.5	81.0		
5812	68.0	97.0		

(Table A-4 continued)

Lab. No.	Results		Other Methods	
	Method 1	Method 2	Results	References
5913	23.0	----		
6112	75.0	86.0		
6424	78.3	104.6		
6715	58.6	121.0		
6811	62.0	73.8		
7222	82.4	78.0		
7424	75.8	91.6		
7512	120.0	187.0		
7522	74.0	44.6		
7526	12.0	127.0		
7722	56.8	91.1		
7813	61.0	55.0		
7922	65.0	116.0		
8512-1	----	----	66.0	7
8512-1	----	----	76.0	8
8512-2	----	----	84.0	7
8512-2	----	----	65.0	8
8512-3	----	----	61.0	7
8512-3	----	----	100.0	8
9111	79.5	106.4		
9113	63.0	----		
9526	80.4	60.0		
9713	76.0	66.0		
9811	70.0	168.0		
9922	100.0	100.0		
9926	225.0	216.0	256.0	13

APPENDIX B.

TESTS FOR NORMALITY AND REJECTION OF OUTLIERS

Test for normality

The Kolmogorov-Smirnov goodness of fit test is used to determine whether the observations reported can reasonably be thought to have come from a normal distribution.*

Briefly, the test involves computing the observed cumulative frequency distribution (the percent of values less than or equal to each value in the distribution) and comparing it to the theoretical normal cumulative frequency distribution. The point at which the two distributions, theoretical and observed, show greatest divergence is determined. Reference of the value of the divergence to a table of critical values for the Kolmogorov-Smirnov goodness of fit test indicates whether such a large divergence is likely on the basis of chance. If such a large divergence is not likely, the distribution is designated as nonnormal; otherwise the distribution is designated as normal.

Tests for rejection of outliers

1. If the distribution is designated as nonnormal, the suspected outlier (the farthest value from the mean) is rejected only if the distance between it and the mean is greater than three standard deviations; otherwise the suspected outlier is accepted.

2. If the distribution is designated as normal and the sample size is less than or equal to 30, the suspected outlier, the farthest value from the mean, is tested for rejection by a method developed by Dixon.** Briefly, the test involves computing a ratio that compares the distance of the suspected value from its neighbors to the range of all or most all of the observations (depending on the exact number in the distribution). Reference of the ratio to a table of critical values for test ratios for gross errors indicates whether such a large ratio is likely on the basis of chance. If the ratio is greater than or equal to the critical value, the

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* S. Siegel. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, Inc. New York, New York. 1956. pp. 47-51.

** W.J. Dixon and F.J. Massey, Jr. Introduction to Statistical Analysis, Second Edition. McGraw-Hill Book Company, Inc. New York, New York. 1957. p. 276.

probability is small the suspected outlier is from the sample distribution, hence, the outlier is rejected. If the ratio is less than the critical value, it is likely that the suspected outlier came from the sample distribution; hence, the suspected outlier is accepted.

3. If the distribution is designated as normal and the sample size is greater than 30, the suspected outlier is tested for rejection by a method developed by Santner.[+] This method employs the following statistic $\frac{\bar{X} - X_o}{s}$, where $\bar{X}$ is the sample mean, X_o is the suspected outlier (the farthest value from the mean), and s is the sample standard deviation. This statistic is compared to a table of critical values to determine whether its value is larger than would be expected on the basis of chance. If the statistic is greater than or equal to the critical value, the suspected outlier is rejected; otherwise, the suspected outlier is accepted.

Application of test for normality and tests for rejection of outliers to ARS studies

The test for normality and subsequent test for rejection of outliers is applied to the observed data in two ways; first, to each method for a given substance at a given level of concentration and then to a given substance at a given level of concentration regardless of method. In either case, it is first necessary to determine whether the original distribution is normal or nonnormal. If the original distribution is designated as nonnormal, method 1 is used to test for rejection of the suspected outlier farthest from the mean. If the suspected outlier is not rejected, no further tests for normality or rejection of outliers are made and the distribution is designated as nonnormal. On the other hand, if the suspected outlier is rejected, the new distribution, which excludes the rejected observation, is then tested for normality. If the new distribution is nonnormal, the next suspected outlier is tested for rejection by method 1; and this cycle of testing for normality and testing for rejection of outliers continues until a suspected value is not rejected or the test for normality designates the distribution as normal. If the distribution is designated as normal, subsequent tests for rejection of outliers made by method 2 or 3 are the same as if the original distribution had been normal. This case is discussed next.

If the original distribution is designated as normal or a new distribution that was originally nonnormal is designated as normal after the rejection of one or more outliers, and if the number of observations is not greater than 30, then method 2 is used to test for rejection the suspected outlier farthest from the mean. If the suspected outlier is

[+] J. Santner. Personal communication.

not rejected, no further tests are made and the distribution is designated as normal. If the suspected outlier is rejected, then the suspected outlier farthest from the mean of the new distribution is tested for rejection and so on until the suspected value of a new distribution is not rejected, at which time no further tests are made and the final distribution is designated as normal. On the other hand, if the number of observations in the original distribution is greater than 30, method 3 is used to test the suspected outlier for rejection. If the suspected outlier is not rejected, no further tests are made and the distribution is designated as normal. If the suspected outlier is rejected, then the suspected outlier farthest from the mean of the new distribution, which excludes the rejected value, is tested for rejection. Testing for outliers continues by this method until a suspected outlier is not rejected or the number of observations is no longer greater than 30, in which case method 2 is used for testing for rejection of any remaining suspected outliers.

APPENDIX C.

GLOSSARY OF STATISTICAL TERMS

A glossary of statistical terms defined as they are used in this report is presented to ensure uniform and complete understanding.

Arithmetic mean	The sum of a series of test results divided by the number of tests in the series.
Median	Halfway point in the readings when they have been arranged in order of size (the middle reading of an odd number of readings, or the average of the middle two for an even number).
Accuracy	The correctness of a measurement, or the degree of correspondence between the results and the true value (actual amount added).
Accuracy data	Measurements that relate to the difference between the average test results and the true value when the latter is known or assumed. The following measures apply:

Average deviation from true value – Average difference (when always considered as positive) between the mean determination for each laboratory and the true value.

Average percent deviation from true value – Average of the differences between a laboratory's replicate results and the true value expressed as percentages of the true value.

Mean error – The average difference with regard to sign of the test results from the true results. Also equal to the difference between the average of a series of test results and the true results.

Relative error – The absolute value of the mean error of a series of test results as a percentage of the true result.

Precision	A measure of the reproducibility of measurements, or the degree to which the measurements correspond to one another.
Precision data	Measurements that relate to the variation among the test results themselves, i.e., the scatter or dispersion of a series of test results without assumption of any prior information. The following measures apply:

Variance – Sum of squares of deviations of the average test results from the mean of the series divided by one less than the total number of average test results.

Standard deviation – Square root of the variance.

Relative standard deviation (coefficient of variation) – Standard deviation expressed as a percentage of the mean of a series of laboratory results.

Range – Difference in magnitude between the highest and lowest laboratory mean.

Average percent deviation within laboratory – Average of the differences between the replicate results from a laboratory and the mean of their results, expressed as percentage of their mean.

Confidence limits – Limits within which the true mean of the population (the theoretically infinite number of possible replications of the analysis) will lie with a given probability.

95% Tolerance limits – Limits within which one can state with chosen confidence that 95% of the individuals of a population will lie.

APPENDIX D.

ANALYTICAL REFERENCE SERVICE MEMBERSHIP

STATE AGENCIES

Alabama State Department of Public Health, Montgomery
Alabama Water Improvement Commission, Montgomery
Arizona State Department of Public Health, Phoenix
Arkansas State Department of Health, Little Rock
California Department of Water Resources, Los Angeles
California Department of Water Resources, Sacramento
California State Department of Public Health, Los Angeles
California State Department of Public Health, Air and Industrial Hygiene Laboratory, Berkeley
California State Department of Public Health, Sanitation and Radiation Laboratory, Berkeley
Colorado Department of Public Health, Denver
Connecticut State Department of Health, Hartford
Delaware Water Pollution Commission, Dover
Florida State Board of Health, Jacksonville
Florida State Board of Health, Miami
Florida State Board of Health, Pensacola
Florida State Board of Health, Winter Haven
Georgia Department of Public Health, Atlanta
Hawaii Department of Health, Laboratories Branch, Honolulu
Hawaii Department of Health, Occupational and Radiological Health Section, Honolulu
Idaho Department of Health, Boise
Illinois Department of Air Pollution Control, Chicago
Illinois Department of Public Health, Springfield
Illinois Department of Public Health, State Sanitary Water Board, Springfield
Illinois State Water Survey Division, Champaign
Illinois State Water Survey Division, Peoria
Indiana State Board of Health, Indianapolis
Iowa State Hygienic Laboratory, Des Moines
Iowa State Hygienic Laboratory, Iowa City
Kansas State Department of Health, Topeka
Kentucky State Department of Health, Division of Laboratory Services, Frankfort
Kentucky State Department of Health, Public Health Laboratories Division, Frankfort
Kentucky State Department of Health, Radiological Health Program, Frankfort
Lawrence Experiment Station, Massachusetts

Louisiana State Board of Health, New Orleans
Maryland State Department of Health, Baltimore
Massachusetts Department of Public Health, Amherst
Massachusetts Department of Public Health, Boston
Michigan State Department of Health, Lansing
Michigan Water Resources Commission, Lansing
Minnesota Department of Health, Engineering Laboratories Section, Minneapolis
Missouri Department of Public Health and Welfare, Jefferson City
Montana Bureau of Mines and Geology, Butte
Montana State Board of Health, Helena
Nebraska Department of Agriculture and Economic Development, Lincoln
Nebraska State Department of Health, Lincoln
Nevada State Department of Health, Las Vegas
Nevada State Department of Health, Reno
New Hampshire Department of Health, Concord
New Hampshire Water Pollution Commission, Concord
New Jersey State Department of Health, Trenton
New Jersey State Department of Health, Environmental Health Laboratories, Trenton
New Mexico Department of Public Health, Sante Fe
New York State Air Pollution Control Board, Albany
New York State Conservation Department, Oakdale, L.I.
New York State Conservation Department, Scottsville
New York State Department of Air Pollution Control, New York City
New York State Department of Health, Albany
North Carolina Department of Water Resources, Raleigh
North Dakota State Department of Health, Bismarck
Ohio Department of Agriculture, Reynoldsburg
Ohio State Department of Health, Columbus
Oklahoma State Health Department, Oklahoma City
Oregon State Board of Health, Division of Sanitation and Engineering, Portland
Pennsylvania Department of Agriculture, Harrisburg
Pennsylvania Department of Health, Bureau of Air Pollution Control, Pittsburgh
Pennsylvania Department of Health, Division of Air Pollution Control, Harrisburg
Pennsylvania Department of Health, Division of Sanitary Engineering, Harrisburg
Puerto Rico Aqueduct and Sewer Authority
Puerto Rico Institute of Health Laboratories, Hato Rey
Rhode Island State Department of Health, Providence
South Carolina Department of Agriculture, Columbia
South Carolina Pollution Control Authority, Columbia
South Dakota Department of Health, Pierre
Tennessee Department of Public Health, Division of Industrial Hygiene Service, Nashville

Tennessee Department of Public Health, Radiological Health Service, Nashville
Tennessee Stream Pollution Control Board, Nashville
Texas State Department of Health, Austin
Utah State Department of Health, Salt Lake City
Vermont Department of Water Resources, Montpelier
Vermont State Department of Health, Barre
Vermont State Public Health Laboratory, Burlington
Virginia State Department of Health, Bureau of Industrial Hygiene, Richmond
Virginia State Department of Health, Bureau of Laboratories, Richmond
Virginia State Water Control Board, Richmond
Washington State Department of Health, Seattle
Washington State Food and Drug Laboratory, Seattle
West Virginia Department of Natural Resources, Charleston
Wisconsin Department of Agriculture, Madison
Wisconsin State Laboratory of Hygiene, Madison

MUNICIPAL AGENCIES

Baltimore Health Department, Maryland
Beaumont Health Department, Texas
Bureau of Air Pollution Control and Heating Inspection, Cincinnati, Ohio
Central District Filtration Plant, Chicago, Illinois
Charlotte Water Department, North Carolina
City of Allentown, Bureau of Water, Pennsylvania
City of Amarillo, Texas
City of Durham, Department of Water Resources, North Carolina
City of Erie, Bureau of Water, Pennsylvania
City of Los Angeles, Department of Water and Power, California
City of Miami, Alexander Orr, Jr. Water Treatment Plant, Florida
City of New York, Department of Health, New York
City of New York, Department of Health, Food and Drug Laboratory, New York
City of Niagara Falls, Division of Water Laboratories, New York
City of Seattle, Washington
City Water Department of Chattanooga, Tennessee
City of Yonkers, Bureau of Water, New York
Department of Health and Hospitals, St. Louis, Missouri
Department of Public Works and Utilities, Flint, Michigan
Department of Service and Buildings, Dayton, Ohio
Easterly Pollution Control Center, Cleveland, Ohio
Erie County Laboratory, Buffalo, New York
Fresno Department of Public Health, California
Houston Health Department, Texas
Long Beach Water Department, California
Los Angeles Air Pollution Control District, California

Los Angeles County Air Pollution Control District, California
Los Angeles County Flood Control District, California
Los Angeles County Sanitation District, Pomona, California (In cooperation with FWPCA)
Los Angeles Department of Public Works, California
Louisville Water Company, Kentucky
Metropolitan St. Louis Sewer District, Missouri
Metropolitan Sanitary District of Greater Chicago, Illinois
Metropolitan Utilities District, Omaha, Nebraska
Metropolitan Water District of Southern California, La Verne, California
Minneapolis Water Department, Minnesota
Monroe County Department of Health, Rochester, New York
Nassau County Department of Health, Hempstead, New York
Nassau County Department of Health, Mineola, New York
Newburgh Water Department, New York
North Jersey District Water Supply Commission, Wanaque
Orange County Air Pollution Control District, Anaheim, California
Pasadena Department of Public Health, California
Philadelphia Department of Public Health, Environmental Health Laboratory, Pennsylvania
Philadelphia Department of Public Health, Public Health Laboratory, Pennsylvania
Philadelphia Suburban Water Company, Bryn Mawr, Pennsylvania
Philadelphia Water Department, Pennsylvania
Philadelphia Water Department, Belmont Laboratory, Pennsylvania
Philadelphia Water Department, Torresdale Laboratory, Pennsylvania
St. Louis County Water Company, Missouri
Springwells Filtration Plant, Dearborn, Michigan
Topeka Water Department, Kansas
Water Pollution Control Board, Cincinnati, Ohio

FEDERAL AGENCIES

Associated Universities Incorporated, Brookhaven National Laboratory, Upton, Long Island, New York
DHEW, Food and Drug Administration, Chicago, Illinois
DHEW, Food and Drug Administration, Division of Pharmacology, Washington, D.C.
DHEW, PHS, Air Pollution Technical Information Center, Division of Air Pollution, Washington, D.C.
DHEW, PHS, Communicable Disease Center, Savannah, Georgia
DHEW, PHS, Division of Dental Public Health, Bethesda, Maryland
DHEW, PHS, Division of Environmental Engineering and Food Protection, Washington, D.C.
DHEW, PHS, Information and Education Office, Division of Air Pollution, Washington, D.C.

DHEW, PHS, Interstate Carrier Branch, Division of Environmental Engineering and Food Protection, Washington, D.C.
DHEW, PHS, Northeast Shellfish Sanitation Research Center, Narragansett, Rhode Island
DHEW, PHS, Northeastern Radiological Health Laboratory, Winchester, Massachusetts
DHEW, PHS, Radiological Health Laboratory, Rockville, Maryland
DHEW, PHS, Regional Office IV, Atlanta, Georgia
DHEW, PHS, Southeastern Radiological Health Laboratory, Montgomery, Alabama
DHEW, PHS, Southwestern Radiological Health Laboratory, Las Vegas, Nevada
District of Columbia Department of Public Health, Washington, D.C.
Fourth U.S. Army Medical Laboratory, Fort Sam Houston, Texas
Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee
Pearl Harbor Naval Shipyard, Honolulu, Hawaii
Regional Environmental Health Laboratory, McClellan AFB, California
San Francisco Bay Naval Shipyard, Vallejo, California
Sixth U.S. Army Medical Laboratory, Fort Baker, California
Tennessee Valley Authority, Chattanooga, Tennessee
Tennessee Valley Authority, Wilson Dam, Alabama
2794th USAF Dispensary, Kelly AFB, Texas
USAF Hospital (HWEBB), Wright Patterson AFB, Ohio
U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland
U.S. Bureau of Sports, Fisheries, and Wildlife, Fish-Pesticide Research Laboratory, Denver, Colorado
USDI, Bureau of Reclamation, Denver, Colorado
USDI, FWPCA, Great Lakes-Illinois River Basins Project, Chicago, Illinois
USDI, FWPCA, Ohio River Basin Project, Wheeling, West Virginia
USDI, FWPCA, Pacific Northwest Water Laboratory, Corvallis, Oregon
USDI, FWPCA, Technical Services Division, Washington, D.C.
USDI, FWPCA, Water Quality Activities, Cincinnati, Ohio
USDI, Geological Survey, Columbus, Ohio
USDI, Geological Survey, Denver, Colorado
USDI, Geological Survey, Little Rock, Arkansas
USDI, Geological Survey, Philadelphia, Pennsylvania
USDI, Geological Survey, Sacramento, California
Walter Reed Army Medical Center, Washington, D.C.
Water Pollution Control Federation, Washington, D.C.

FOREIGN AGENCIES

British Coke Research Association, Chesterfield, Derbyshire, England
Central Electricity Research Laboratories, Leatherhead, Surrey, England
City's Institute for Health Protection, Belgrade, Yugoslavia

Comissao Inter-Municipal de Controle da Poluicao das Aguas E Do Ar, Sao Paulo, Brazil
Department of Energy, Mines and Resources, Ottawa, Ontario, Canada
Department of Health Services and Hospital Insurance, Vancouver, Canada
Department of Municipal Laboratories, Hamilton, Ontario, Canada
Department of National Health and Welfare, Vancouver, Canada
Department of National Health and Welfare, Occupational Health Division, Ottawa, Ontario, Canada
Department of National Health and Welfare, Public Health Engineering Division, Ottawa, Ontario, Canada
Instituto Nacional de Obras Sanitarias, Caracas, Venezuela
Israel Institute of Technology, Haifa
Metropolitan Corporation of Greater Winnipeg, Manitoba, Canada
Metropolitan Water, Sewage, and Drainage Board, Sydney, Australia
Ministere de la Sante, Montreal, Quebec, Canada
National Institute of Hygienic Sciences, Tokyo, Japan
National University of Colombia, Bogota
Newcastle and Gateshead Water Company, Newcastle Upon Tyne, England
Obras Sanitarias de la Nacion, Buenos Aires, Argentina
Ontario Water Resources Commission, Toronto, Ontario, Canada
Osaka City Institute of Hygiene, Japan
Permutit Company, Limited, London, England
Public Health Laboratory Service, London, England
Scientific Research Council, Kingston, Jamaica, West Indies
Taiwan Institute of Environmental Sanitation, Air Pollution and Radiological Health Section, Taipei, Taiwan, China
Taiwan Institute of Environmental Sanitation, Division of Water Quality and Pollution Control, Taipei, Taiwan, China
Taiwan Institute of Environmental Sanitation, PHA, Taiwan, China
Taiwan Institute of Environmental Sanitation, Taichung Water Laboratory, Taichung, Taiwan, China
Taiwan Institute of Environmental Sanitation, Tainan Water Laboratory, Tainan, Taiwan, China
Taiwan Institute of Environmental Sanitation, Taitung Water Laboratory, Taitung, Taiwan, China
Taiwan Institute of Environmental Sanitation, Training Section, Taipei, Taiwan, China
United Kingdom Atomic Energy Authority, Didcot, Berks, England
University of Beograd, Yugoslavia
University of Leeds, England
Waste Water Research Laboratory of the Swedish Forest Industries, Stockholm, Sweden
Water Research Association, Marlow, Buckinghamshire, England

UNIVERSITIES

University of California, Richmond
University of California, Riverside

University of California, Engineering Material Laboratory, Berkeley
University of California, Industrial Hygiene Engineering, Berkeley
Clemson University, South Carolina
Columbia University, Plainsboro, New Jersey
Cornell University, Ithaca, New York
University of Dayton, Ohio
Drexel Institute of Technology, Philadelphia, Pennsylvania
Fairleigh Dickinson University, Madison, New Jersey
University of Florida, College of Engineering, Gainesville
Iowa State College, Ames
University of Kansas, Lawrence
Louisiana State University, Baton Rouge
University of Minnesota, Minneapolis
New York University Medical Center, New York
University of North Carolina, Chapel Hill
University of Pittsburgh, Pennsylvania
Purdue University, Lafayette, Indiana
Rennselaer Polytechnic Institute, Troy, New York
Rutgers – The State University, Department of Agricultural Chemistry, New Brunswick, New Jersey
Rutgers – The State University, Department of Environmental Science, New Brunswick, New Jersey
St. Mary's College, Winona, Minnesota
University of Vermont, Burlington
Washington State University, Pullman

INDUSTRIES

American Bio-Chemical Laboratory, Incorporated, Baltimore, Maryland
American Cyanamid Company, Wayne, New Jersey
Anaconda Company, Grants, New Mexico
Battelle Memorial Institute, Columbus, Ohio
Bethlehem Steel Company, Bethlehem, Pennsylvania
Bio-Technics Laboratories, Incorporated, Los Angeles, California
Borg-Warner Corporation, Des Plaines, Illinois
Brown and Caldwell Laboratories, San Francisco, California
Calgon Corporation, Pittsburgh, Pennsylvania
California Water Service Company, San Jose, California
Chrysler Corporation, Detroit, Michigan
Controls for Radiation Incorporated, Sandusky, Ohio
Culligan Incorporated, Northbrook, Illinois
Cyrus Wm. Rice and Company, Pittsburgh, Pennsylvania
Dow Chemical, Midland, Michigan
E.I. du Pont de Nemours and Company, Aiken, South Carolina
Ekroth Laboratories, Incorporated, Brooklyn, New York
Emery Industries, Incorporated, Cincinnati, Ohio
FMC Corporation, Pocatello, Idaho

Fairbanks, Morse and Company Research Center, Beloit, Wisconsin
General Electric Company, Louisville, Kentucky
Good Year Atomic Corporation, Piketon, Ohio
H.C. Nutting Company, Cincinnati, Ohio
Hammond-Montel, Incorporated, Elmhurst, New York
Havens-Emerson, Oradell, New Jersey
Hazleton Nuclear Science Corporation, Palo Alto, California
Holzmacher, McLendon and Murrell, Melville, New York
Industrial Chemicals, Incorporated, South Bend, Indiana
INFILCO, General American Transportation Corporation, Tucson, Arizona
Ionics, Incorporated, Watertown, Massachusetts
Johns-Manville Research and Engineering Center, Manville, New Jersey
Kem-Tech Laboratories, Incorporated, Baton Rouge, Louisiana
Kennecott Copper Corporation, Salt Lake City, Utah
Magnus Chemical, Garwood, New Jersey
Mallinckrodt Chemical Works, St. Louis, Missouri
Maryland Cooperative Milk Producers, Incorporated, Baltimore, Maryland
McCrone Associate, Incorporated, Chicago, Illinois
Midwest Research Institute, Kansas City, Missouri
Minute Maid Company, Anaheim, California
Monsanto Company, St. Louis, Missouri
NALCO Chemical Company, Chicago, Illinois
New Mexico Institute of Mining and Technology, Socorro
Nuclear-Chicago Corporation, Des Plaines, Illinois
Pacific Gas and Electric Company, Emeryville, California
Pacific Gas and Electric Company, San Francisco, California
Pan American World Airways, Patrick Air Force Base, Florida
Pomeroy, Johnston and Bailey, Pasadena, California
Radiation Applications, Incorporated, Long Island, New York
Radiation Detection Company, Mountain View, California
Ray W. Hawksley Company, Incorporated, Richmond, California
Reynolds Electrical and Engineering Company, Incorporated, Industrial Hygiene, Las Vegas, Nevada
Reynolds Electrical and Engineering Company, Incorporated, Radiological Sciences Department, Las Vegas, Nevada
Roy F. Weston, Incorporated, West Chester, Pennsylvania
Sandia Corporation, Albuquerque, New Mexico
Shell Chemical Company, Princeton, New Jersey
Southern Testing and Research Laboratories, Incorporated, Wilson, North Carolina
Tracerlab, Incorporated, Richmond, California
U.S. Industrial Chemicals Company, Tuscola, Illinois
W.R. Grace and Company, Dearborn Chemical Division, Lake Zurich, Illinois
Wastewater Analysis Corporation, Lincon Park, Michigan
Water Service Laboratories, Incorporated, New York, New York
York Research Corporation, Stanford, Connecticut